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Building highway landscapes: innovative directions for urban wastewater treatment in the face of new challenges in China

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Abstract

Urban development in China has caused many problems of urban water management. Today we have to face new challenges about decreasing water resources, wastewater treatment, limited spaces and ecological preservation. Solving these problems should be in sustainable ways with innovative approaches. This paper proposed a highway landscape strategy that contains four major green directions for urban water management. The strategy combined several disciplines of ecology, civil engineering, landscape design and agricultural irrigation. This conceptual idea is demonstrated through a design of a complex constructed wetland system for Huai'an city wastewater plant in Jiangsu province, which sits on the East-route Water Transfer Project of China. The designed project in this paper consists of retention facilities, ecotype corridors, surface flow wetlands and stabilization ponds. Especially, it is designed beside a highway around the city. Normally, the whole system could treat effluents from wastewater plants and irrigation fields. In rainy seasons, it could store and treat extra urban sewer discharges and road surface runoff. During farming season, it is also designed that the outflow of the system would be reused to irrigate. Moreover, this proposal illustrated that the landscape design of the system on a highway side could achieve multiple benefits for the highway surrounding environment. It would provide as much education, recreation, and habitat creation as possible to local community.

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Keywords: highway landscapes; urban development; wastewater treatment; complex constructed wetland system; ecological design; water reuse; low carbon; sustainable ways

1. Introduction

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In 2010, according to the report of 2011 from National Bureau of Statistics of China, the people in cities have increased about 13.5% compared with the year of 2000. Urban expanding in China is becoming an inevitable trend. Nearly all of cities are facing water and wastewater management challenges. Improving urban water quality in low-cost and low carbon ways will be critical in moving towards a sustainable future. Constructed wetlands have been used worldwide to improve water quality for domestic reuse, irrigation and environmental protection [1]. These systems are most often designed by engineers who focus primarily on treatment function rather than landscape design, so the potential value of beautiful landscapes will be neglected. Meanwhile, these systems will occupy lots of limited spaces in cities and the land value in use is not efficient.

In the face of decreasing water resources, wastewater treatment, limited spaces and ecological preservation, this paper first presents four key design directions for urban wastewater treatment of the future. These directions will be applied in conjunction to make urban wastewater management more sustainable and effective. The four directions are: 1. separated infrastructures and limited spaces utilization, 2. low carbon design based on ecological processes, 3. a wide variety of effluent collection and reuse of treated water, 4. multifunctional systems that benefit human and ecological community. The article then describes a case study which demonstrates these functions for Huai'an city wastewater plant in Jiangsu province. This designed system is a self-sustainable system and it will have multifunction in the future such as the reuse of treated wastewater, to create a biodiversity natural habitat and to educate the students and visitors on important of our precious natural resource. Though the whole system is not fully in operation yet, this design proposal is intended to discuss the feasibility and value of such system. And it also may lead a direction for the development of urban wastewater management in China.

2. Green directions for urban wastewater treatment of the future in China

Conventional wastewater treatment plants involve large capital investments and operating costs [2]. Meanwhile, these traditional plants always focus on single treatment function rather than on multi-functions. This article presents some beautiful and green ways to address urban water quality challenges.

First, wastewater treatment plants in the future should provide resilience against human or natural disasters. In this paper, we proposed separated infrastructures to allow several treatments flexibility. Compared with the traditional ones, this system is spatially adaptive and allows each treatment for a particular site or neighbourhood. There are smaller pipe networks between these separated infrastructures, so it is less prone to catastrophic failure.

In China, because of the large population, the spaces are very limited in urban area. It is an important role to consider the land use efficiency. Not to waste the land potential value is the sustainable way that the designers should insist on in the future. The proposed constructed wetland system discussed later is designed beside a highway. This design concept not only used the large free lands around cities, but also beautified the landscape on the way.

Second, wastewater plants should depend on natural treatment processes and low-carbon systems to improve water quality. Natural treatment systems rely on vegetative and microbial metabolism with little energy consumption. It is green and low-carbon, such as the proposed system in this paper. Through this whole constructed wetland system, we could see the natural treatment processes under solar power mainly. These human-built system that draw from nature's lessons have been shown to be efficient, attractive, and inexpensive worldwide [3].

Meanwhile, in urban contexts, the existing sewerage is aging, undersized and insufficient in China, and it is still a conventional centralized sewer system. This proposed system can provide relief for combined sewer networks, and they can be used as the tertiary wastewater treatment.

Third, in the face of tightening water quality, quantity and carbon emission regulations, wastewater infrastructure should detain, treat and reuse a wide variety of effluent resources. The proposed system collects urban stormwater, irrigation water, flood, highway runoff and urban wastewater.

In China, the potable water resources are very limited. So, an important direction is that wastewater treatment system should provide recycled water for local reuses. To replace and reduce potable water, the recycled water is used to flush toilets [4], fight fires, clean streets, irrigation [5] and river rehabilitation [6]. By treating and reusing the wastewater from residents and surface runoff, cities can save precious freshwater resources [7].

Additionally, wastewater treatment system is not only an infrastructure, but also a garden which we can call landscapes. They should have multiple functions such as recreation, education and habitat to local communities. The proposed system discussed later will be built beside highways around the city. It is a beautiful landscape for the drivers on the way and also the first impression of the city for travelers.

3. Case study

3.1. Background

In 2002, China launched the South-to-North Water Transfer Project in context of water shortage in the acid north [8, 9]. The project consists of three south-to-north canals (i.e., East, Middle, and West), stretching more than 1,000 km across the east, middle, and west parts of China [10]. This complex constructed wetland system is designed for the wastewater plant of Huai'an city, which sits on the East-route Water Transfer Project of China (Figure 1.). It's more important to control the water quality along the East Water Transfer Route.

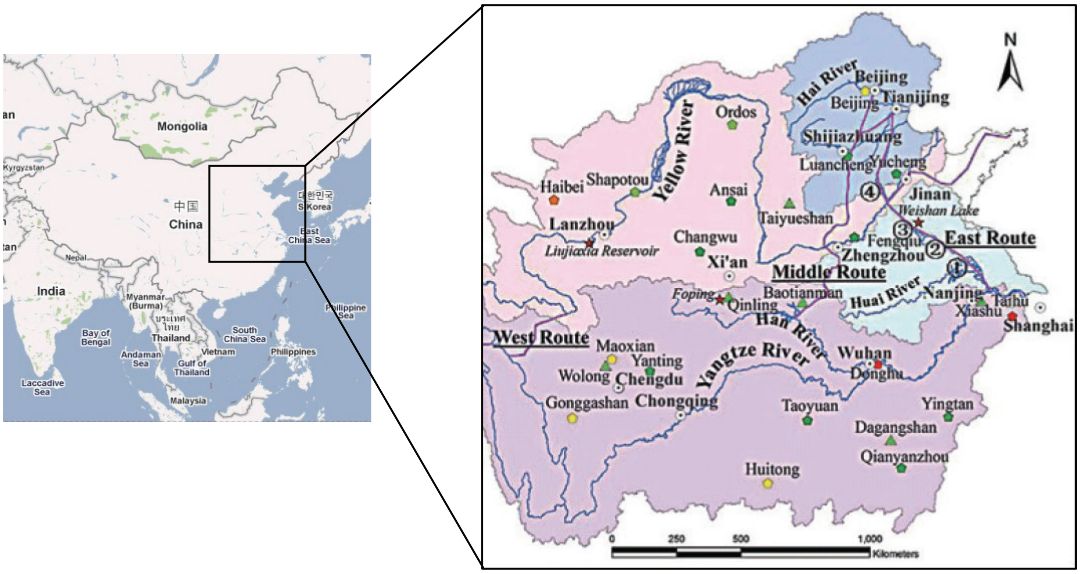

Fig. 1. East-route Water Transfer Project of China

Huai'an is a developing city with population increasing and industry prospering. The wastewater volume has exceeded the capacity of old treatment plans. On the other hand, the city operates an old combined sewer system. During heavy rain events, large volumes of stormwater will exceed treatment plant capacity. These large discharges of untreated and poorly treated wastewater will be received by the White Horse Lake which has been eutrophicated during these years. The yearly mean phosphorus concentration of the lake water is 0.12-0.3 mg/L. According to the district government's layout, the White Horse Lake was selected as the standby freshwater source in 2009. Therefore, it is urgent and vital to clean and protect the freshwater source.

Moreover, Hongze district in Huai'an city is a farming land which needs large volume of water to irrigate. So, it is opportune to explore this designed system with solar powered, multi-functional wastewater treatment for water irrigation reuse.

3.2. Materials and Methods

According to the directions above, this proposed system is located beside the Ning-Lian highway across Huai'an city (Figure 2.). The system building zone is about 200m wide and 7,000m long. The whole system consists of retention facilities, ecotype corridors, free water system wetlands and stabilization ponds. It's designed to treat amount of 90,000 m^3 of wastewater per day. There are two wastewater treatment plants (1#, 2#) we should consider in design. Therefore, the system contains almost two sets of infrastructures to purify the wastewater separately except the last stabilization pond (Figure 3.). In this design, some measures were adjusted to local conditions. We used and altered the old local fish ponds and farming areas to build water retention ponds and free water system wetlands.

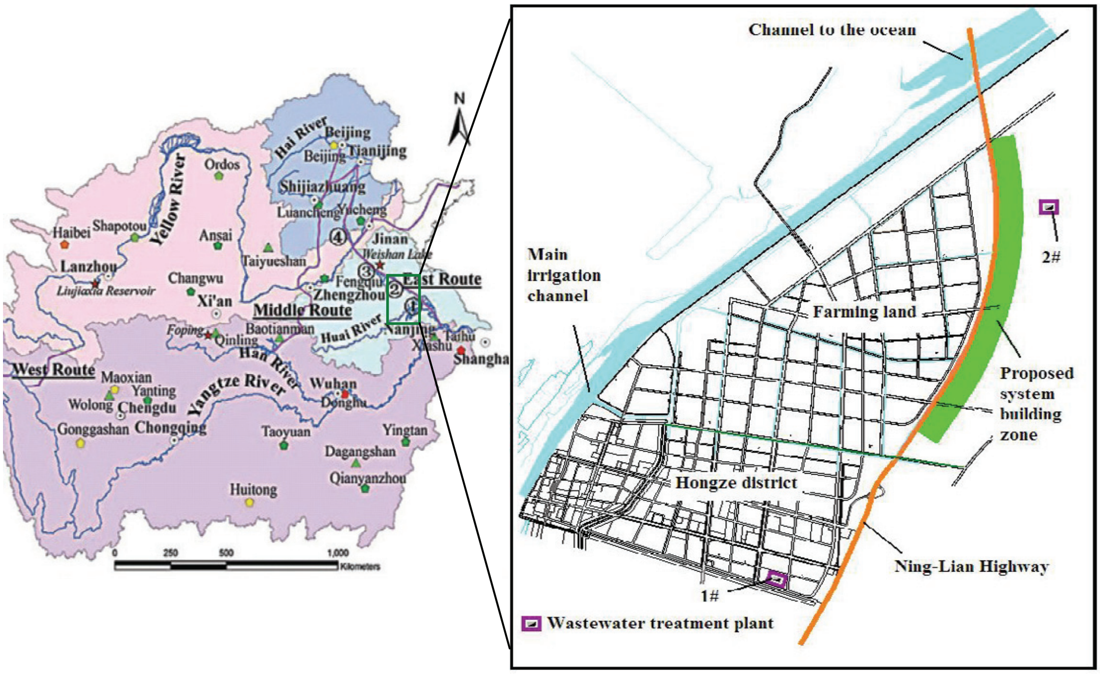

Fig. 2. Study area and Location of the proposed ecosystem

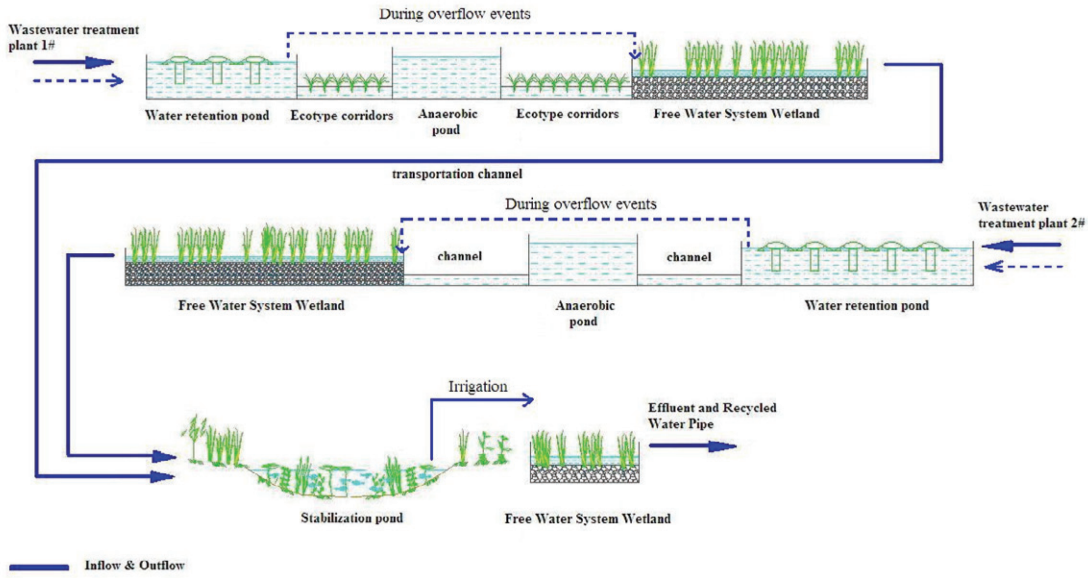

Fig. 3. Flowchart and Hydraulic of the proposed complex constructed wetland system

In the water retention pond, the design team added solar powered aeration machines to help increase the oxygen level of the wastewater. Around the retention pond, we planted reeds (Phragmites australis) and water bamboo (Zizania latifolia) to absorb nitrogen and phosphorous from the wastewater. To protect the banks from erosion, we selected vetiver grass which has a deep thick root system [11]. The retention pond 1# is about 104,000 m^2, and pond 2# is about 120,000 m^2. The hydraulic retention time (HRT) is about 9 days. The total storage capacity for water in two ponds is about 900,000 m^3. We also considered some urgent situations such as regional waterlogging or a sudden failure of wastewater plants, and then a large volume of overflows could be discharged into the water retention pond directly. During these overflow events, the HRT will be shorten and the extra mixed wastewater will be pumped to the constructed wetland downstream.

The ecotype corridor is designed and built based on the old irrigation channel in order to connect retention pond, anaerobic pond and free water system wetlands. Its total length is about 1,100 m with the average slope of 1‰. Its 0.6 m deep substrate consists of a mixture of gravel and crushed rock, which has a high binding capacity for phosphorus [12]. On the both sides of the corridor we plant several kinds of flowers like calamus, Thalia dealbata and orris to decorate the environment.

The anaerobic pond is designed as a part of water retention facilities. Its main purpose is to make up an anoxic/oxic (A/O) system with retention ponds and corridors. As we know, this system can remove carbon and nitrogen simultaneously. At the same time, we planted some algae in pond and Typha on the surrounding surface near bank. So, we would find the symbiosis between bacteria and alga which could help to treat the wastewater efficiently. The anaerobic pond's area in all is about 175,000 m^2, and its storage capacity for water is about 788,000 m^3. The HRT is about 8 days.

The free water system wetland in this design is on the basis of original agricultural lands. With dikes surrounding wetlands, we also planted reeds, cannas, orris and Typha latifolia in it to make it as a decorative element in the whole landscape. Meanwhile, in order to increase the HRT, we dug many curving ditches in wetlands. The total free water system wetland has an area of 796,000 m^2 with an average slope of 1.5‰. Its hydraulic loading rate (HLR) is about 0.14 m/d and the free water depth in it should be controlled at no more than 0.4 m.

The final part is the stabilization pond which is used to gather the clean water from wetlands and is designed as a beautiful lake for the community. It has an area of 138,000 m^2 and a depth of 1.6 m (HRT = 2.5 days). In pond, we planted a few of floating aquatic plants like water lily, spatterdock and water chestnut to add a contrast of colour in the sceneries. On the other hand, this pond is also an irrigation pond from which the water will be pumped into the farming land. Within the pond design, there is a running loop around the pond for walking and jogging.

Furthermore, the monitoring on-line system was built. It's necessary to take wastewater samples from every infrastructure effluent to monitor the effectiveness and to adjust the flow rate of the system.

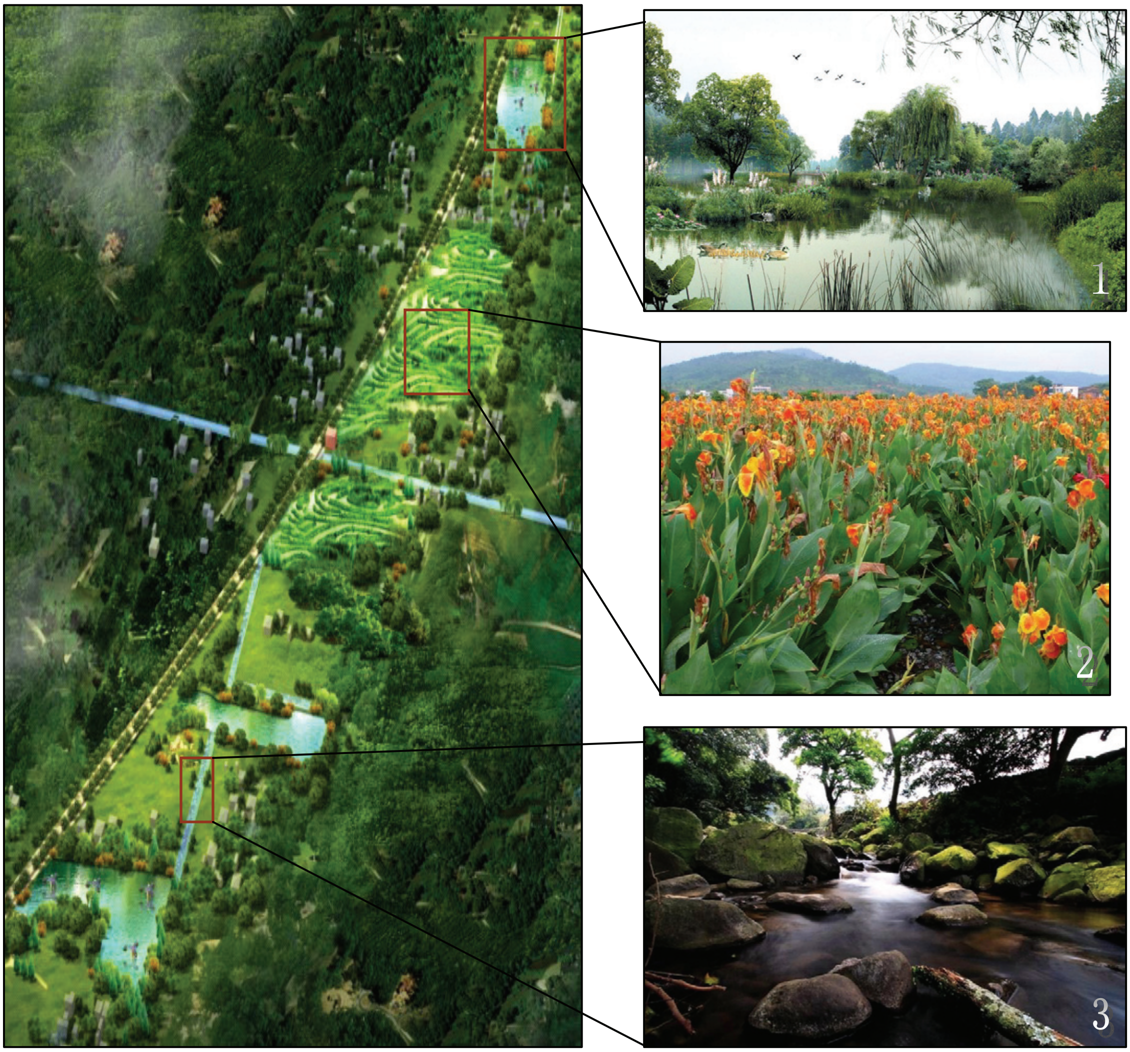

Fig. 4. The bird's eye view of this designed system. (1. Stabilization pond, 2. Free water system wetland, 3. Ecotype corridor)

4. Discussion

This proposed system has just been completed when this paper is written. The system cannot fully in operation now, and we still should adjust the flow rate, HRT and the initial discharge of the wastewater into the system. After a period of operation, we need to monitor whether the removal rates of COD_{cr}, BOD, NH_3-N and TP achieve the anticipated effect of treatment.

In rainy seasons, the system could store and treat extra urban sewer discharges and highway surface runoff through the pipe connected with the sewer network to the retention pond directly. During farming season, it is also designed that the outflow of the system would be reused to irrigate. Based on a simple first-order plug flow volumetric loading model: C(out)/C(in) = e (-k*t), HRT = V/Q [13], we could moderate the inflow volume to the wetland on every scenarios using pump stations.

In the design, we utilized the gravity most as the whole system's momentum, including some pump stations and siphons. Whatever in ponds or wetlands, we must make sure that plants do not occupy more areas and cover the entire pond. That situation will destroy the ecosystem around and reduce the effectiveness of the whole designed system. We placed a rhombus barrier made of PVC piping to solve this problem. To demonstrate and educate the visitors on the theory of sustainable design, a sprinkler system has been built which pumps the water from stabilization pond to clean the garden and water the landscape all seasons. Several educational signs were placed everywhere to introduce the plants and explain how the system operates.

According to the former experiences, we estimate the whole system will reach its full operating capacity after 12 months to 18 months. But in the next 5 months, many flowers will be blooming and we will have a beautiful garden beside the Ning-Lian highway.

5. Conclusions

This paper introduced several directions to wastewater treatment and reuse today, using a complex constructed wetland system for a combined sewer network and an aging, undersized wastewater treatment plant. Moreover, this proposal illustrated that the landscape design of the system on a highway side could achieve multiple benefits for the highway surrounding environment. It would provide as much education, recreation, and habitat creation as possible to local community.

Although this proposed system has so many benefits such as water reuse, low carbon, less cost and landscapes for the community, it is important to know that in urban or other industrial countries, these natural treatment systems cannot fully replace the conventional wastewater treatment plant.

The lifetime of the whole system is a significant problem. Successful applications of this proposed system need to rely on ecological materials and require more care about their design and operation. More efforts should be made to decipher the plant treatment mechanisms and moderate the related parameters, so as to provide more effective approaches for the natural wastewater treatment systems.

In China, even all the world, we human should face the shortage of freshwater resources and the deteriorating ecological environment. Sustainable way is fast becoming a globally issue, especially in water management field. Moreover, the engineers should master and use multidisciplinary approaches to solve tomorrow's new problem. Innovative directions will be required and we hope this initial ecosystem may provide experiences to the water purification of the future.

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